Behind the scenes of CESM development

The Art of Tuning and Coupling

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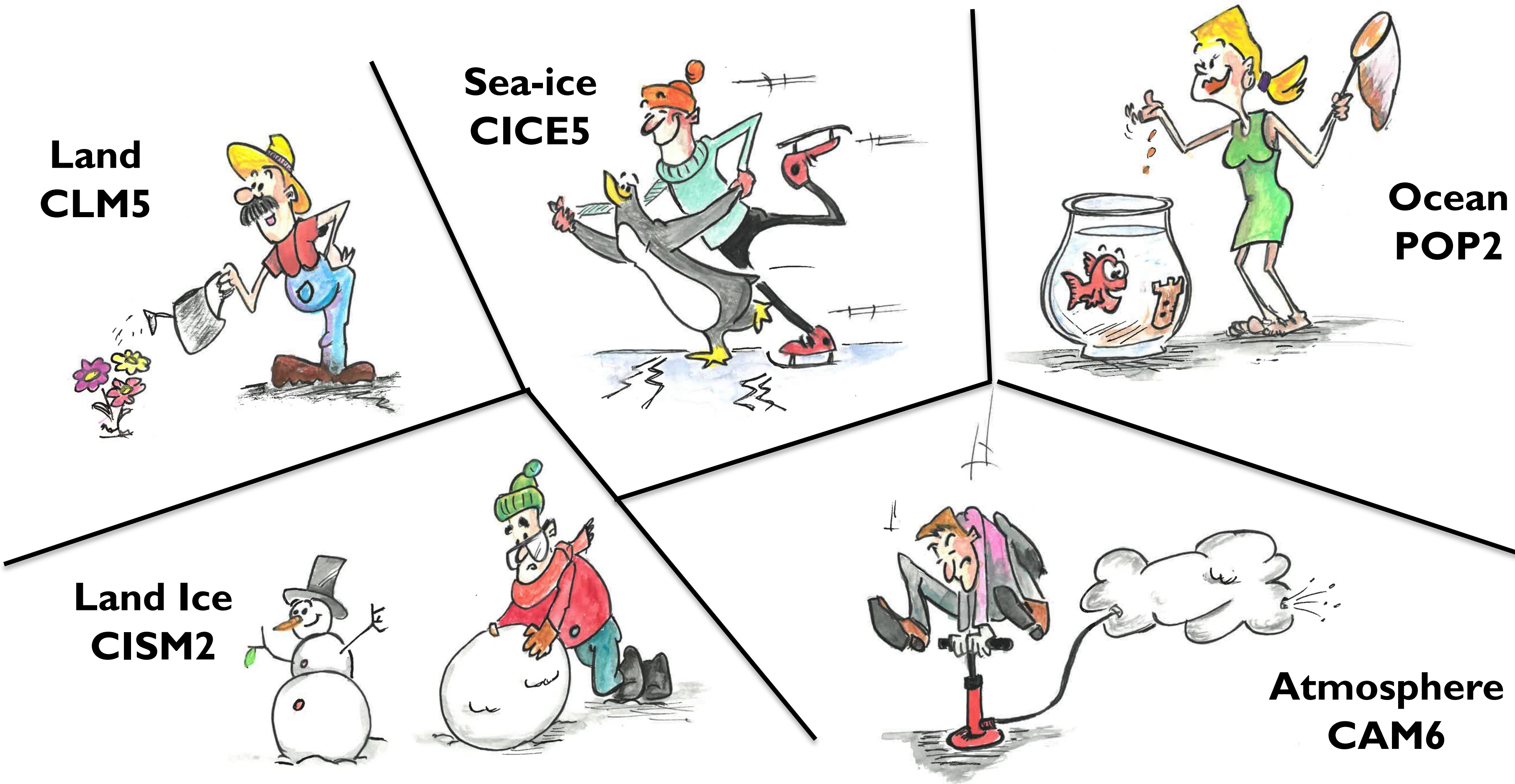
CESM2: Development of the individual components

Phase 1: "Let's build it" (5 years)

- Individual components were built within each working group
- Effort started around 2010

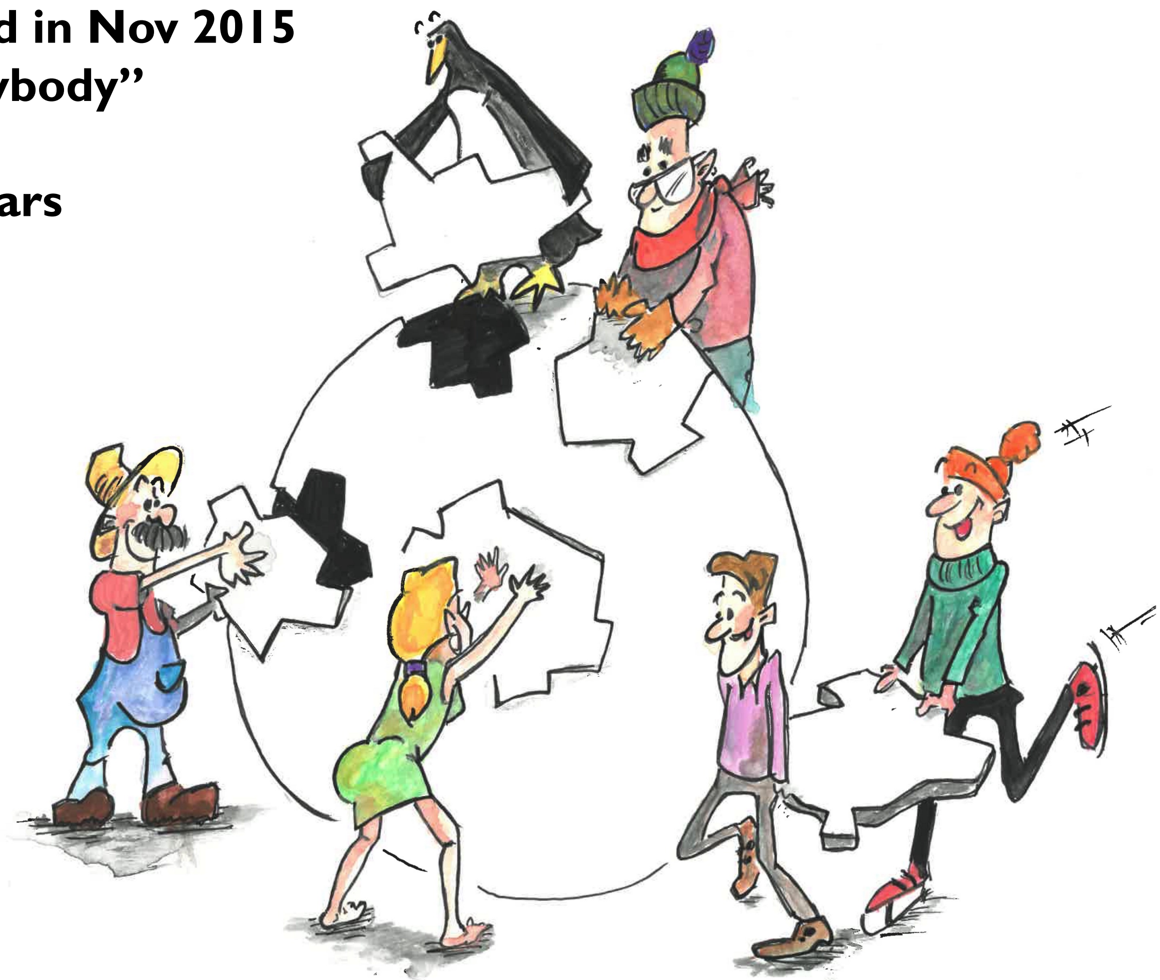


CESM2: Coupling of the individual components

Phase 2: "Let's put it together" (3 years)

- Collaborative effort started in Nov 2015
- Many meetings with "everybody"
- 300 configurations
- Thousands of simulated years and diagnostics

CESM2 Release: June 2018



Development requires: Tuning and Coupling

In this talk, we'll focus on these aspects

The Art of Tuning

Model tuning

Tuning = adjusting parameters ("tuning knobs") to achieve best agreement with observations.

Model tuning

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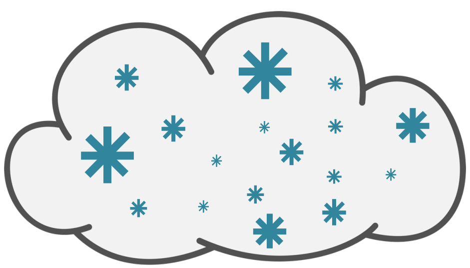
Tuning knobs = parameters weakly constrained by observations

Dcs = Threshold diameter to convert cloud ice particles to snow



Cirrus clouds

- **cloud made up of ice crystals**
- **altitudes higher 5 km**
- **big ice crystals fall out of the cloud => cloud ice "convert" to snow**

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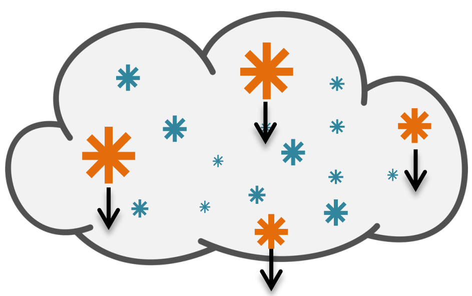

Cirrus clouds

- cloud made up of ice crystals
- altitudes higher 5 km
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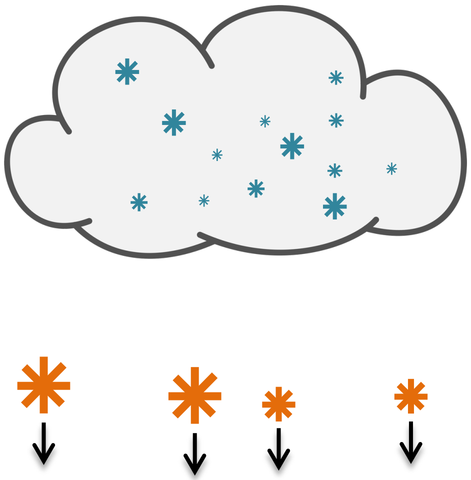
Dcs = threshold diameter *

Model tuning

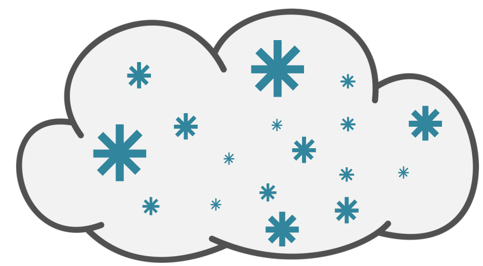
Dcs = Threshold diameter to convert cloud ice particles to snow

Smaller Dcs



Less cloud ice

Larger Dcs



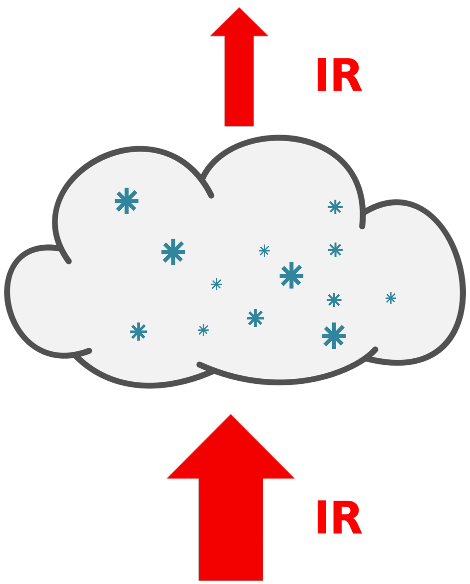
More cloud ice

What is the impact on climate ?

Model tuning

Dcs = Threshold diameter to convert cloud ice particles to snow

Smaller Dcs



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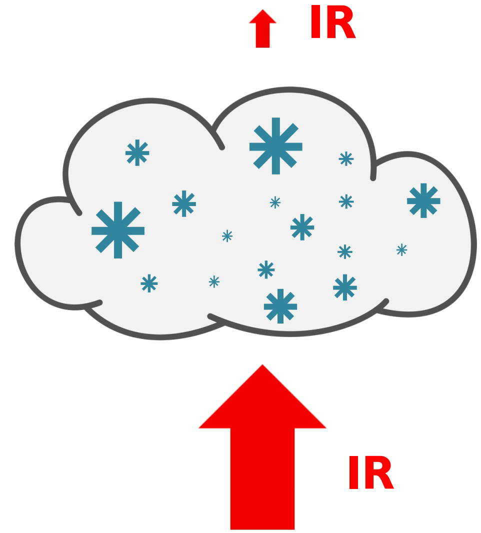
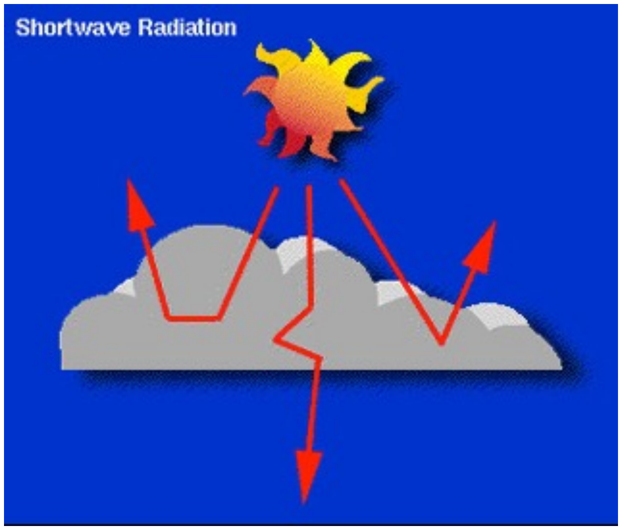


More cloud ice

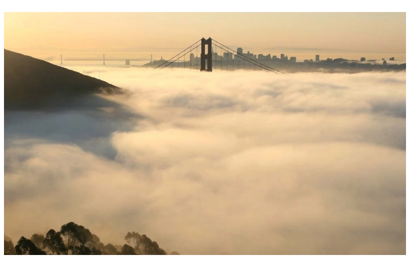
More cloud ice => less infrared radiation (IR) go to space

Aside: Cloud forcing

Shortwave (solar) radiation

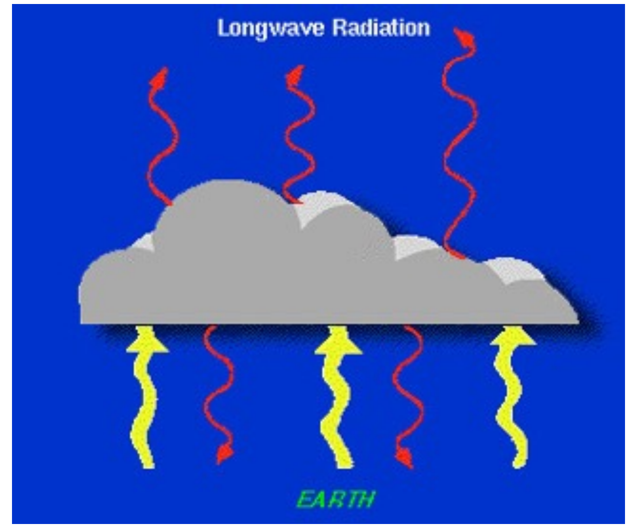


Shortwave radiation comes from the sun
Shortwave is scattered by clouds.
Many of the rays return to space.
⇒ Cooling of the Earth

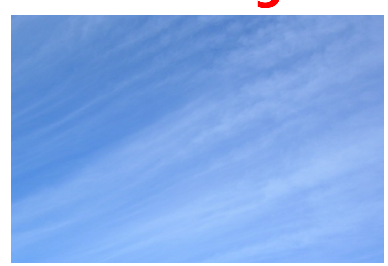


Typical impact for stratocumulus

Longwave (IR) radiation



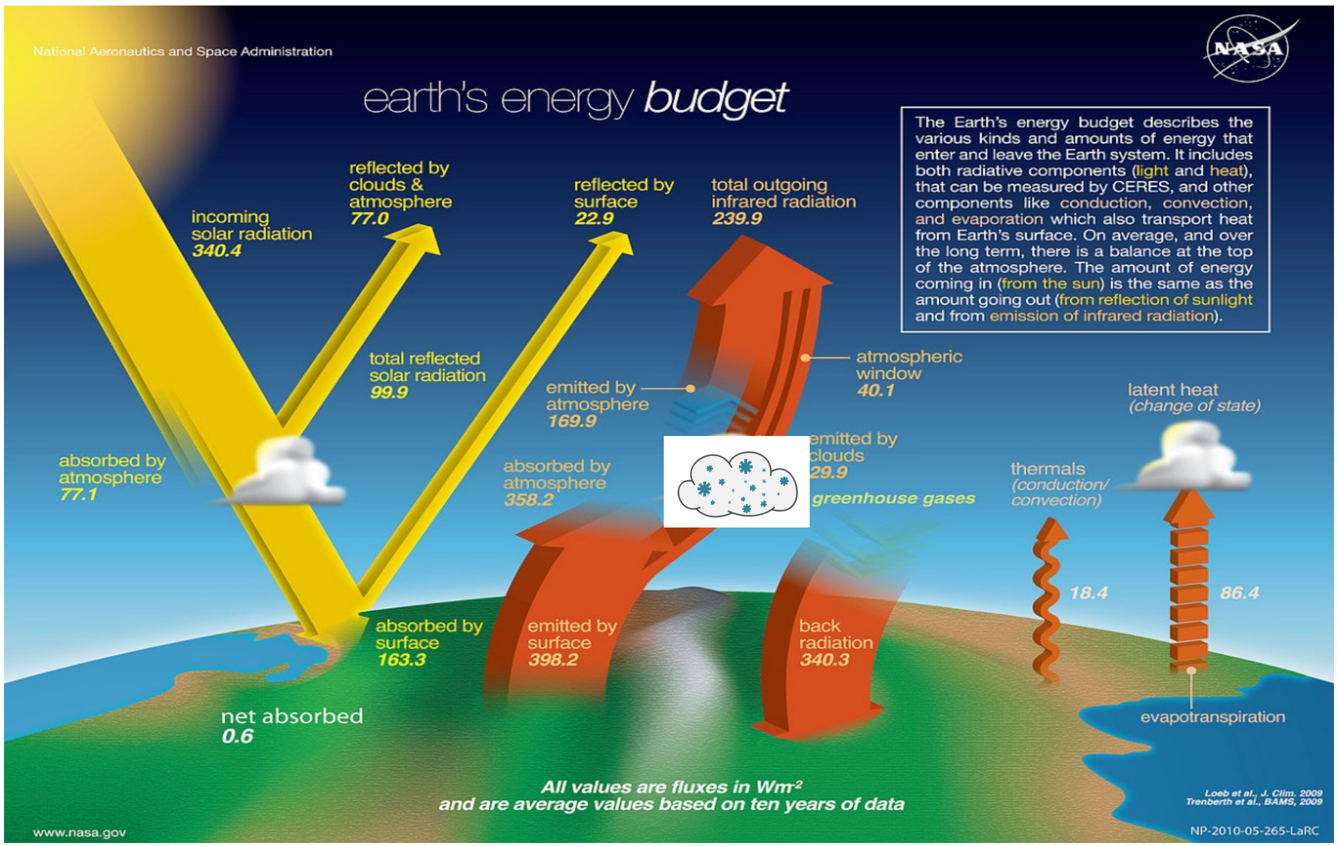
Longwave rays emitted by the Earth
Longwave absorbed/reemitted by clouds
Some rays going to the surface.
=> Warming of the Earth



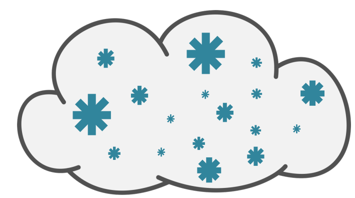
Typical impact for cirrus cloud

Model tuning

Tuning = adjusting parameters ("tuning knobs") to achieve best agreement with observations.



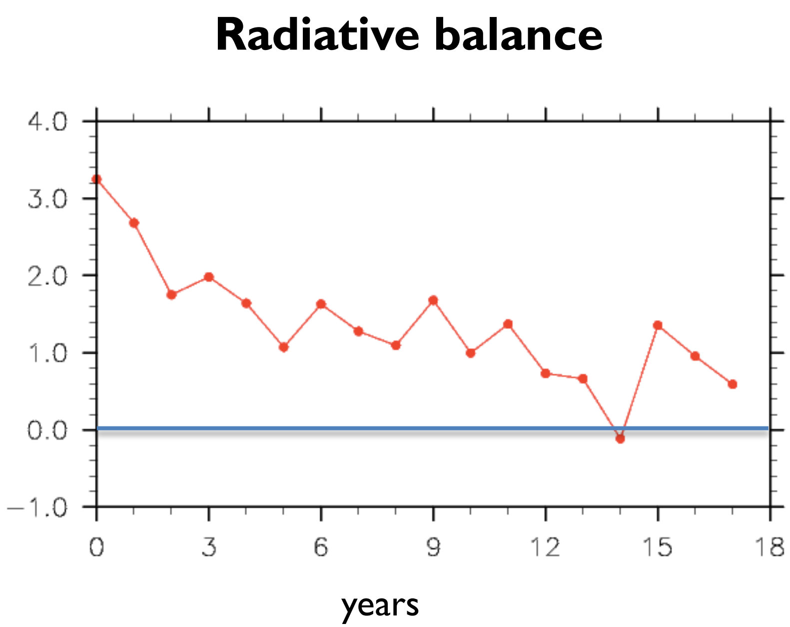
Adjust Dcs

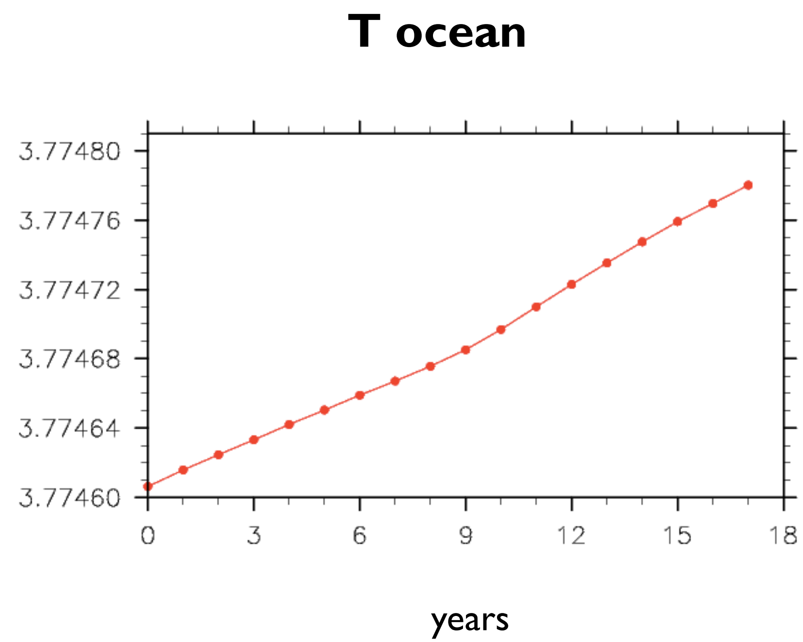


Top of atmosphere radiative balance should be near zero

Model tuning

Why is it so important to tune atmosphere radiative balance ?





If the atmosphere radiative balance is positive, the ocean is warming

Model tuning

Top of atmosphere radiative balance should be near zero

Other targets when tuning

- Cloud forcing
- Precipitation
- ENSO amplitude
- AMOC
- Sea-ice thickness/extent

Dilemmas while tuning

- **Subjectivity of tuning targets**

  Tuning involves choices and compromises
  Overall, tuning has limited effect on model skills

- **Tuning for pre-industrial ⇔ Tuning for present day**

  Pre-industrial: Radiative equilibrium
  Present day: Available observations

- **Tuning individual components ⇔ Tuning coupled model**

  Tuning individual components is fast
  But no guarantee that results transfer to coupled model

- **Tuning exercise is very educative**

  We learn a lot about the model during the tuning phase.

The Art of Coupling

Coupling = Unleashing the Beast

AMIP run

- Prescribed SSTs
- No drift

Coupled run

- Fully active ocean
- Coupled bias and feedback

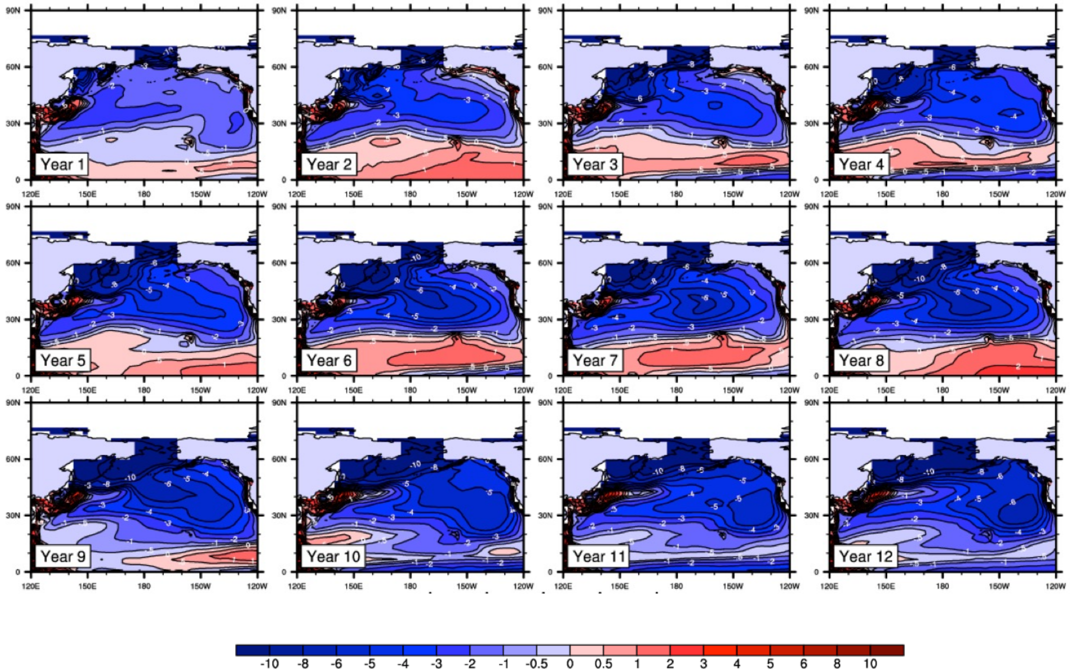
SSTs = Sea Surface Temperatures
AMIP = type of run when SST are prescribed

Example of unleashing the beast (1)

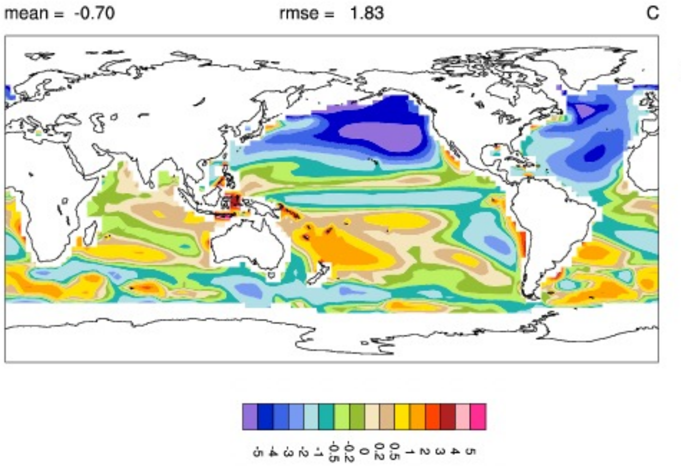
Tuning CAM5 (CESM1 development, 2009)

- Tuning was done in AMIP mode: looks like "perfect" simulation
- In coupled mode: strong cooling of the North Pacific (bias > 5K)

Evolution of the SST errors (K)



Mean SST errors (K)



Courtesy Rich Neale

CAM = Community Atmospheric Model
SST = Sea Surface Temperature
AMIP = type of run when SST are prescribed

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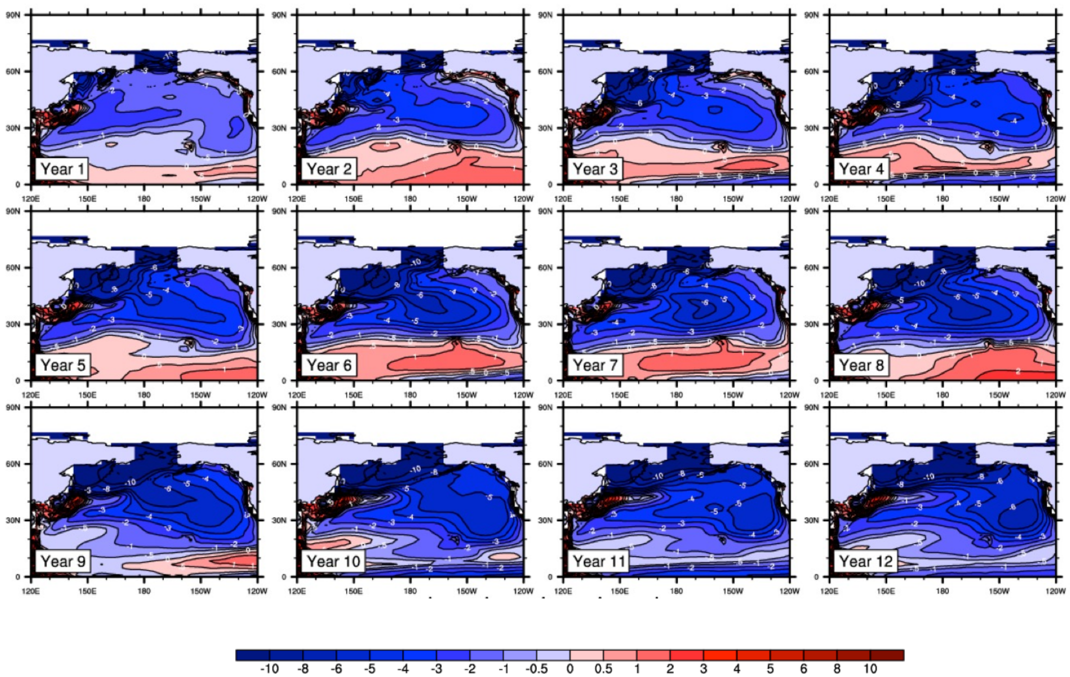
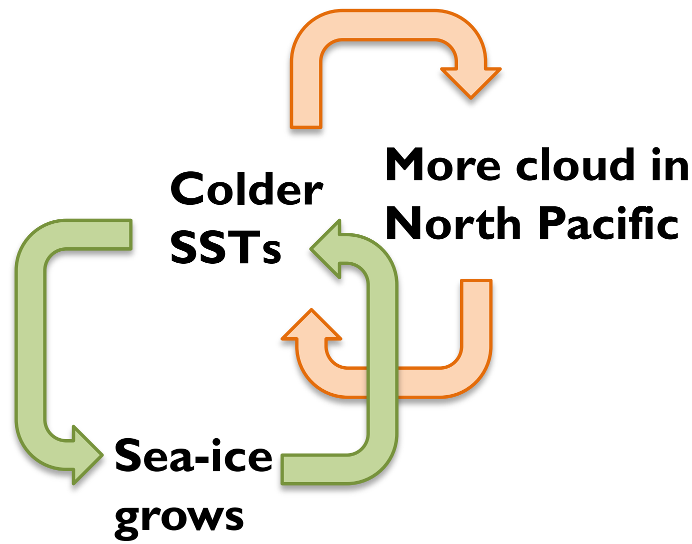




Courtesy Rich Neale

Coupling = Unleashing the Beast

Example of unleashing the beast (2)

Spectral Element dycore development (CESM1.2, 2013)

Finite Volume (FV)

Lat-lon

Spectral Element (SE)

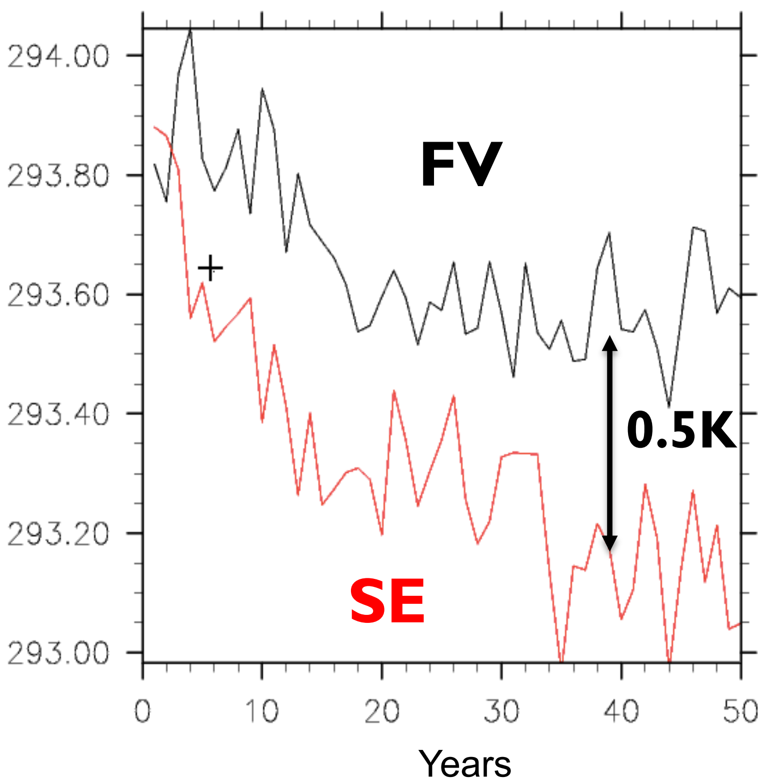
Cubed-sphere

Example of unleashing the beast (2)

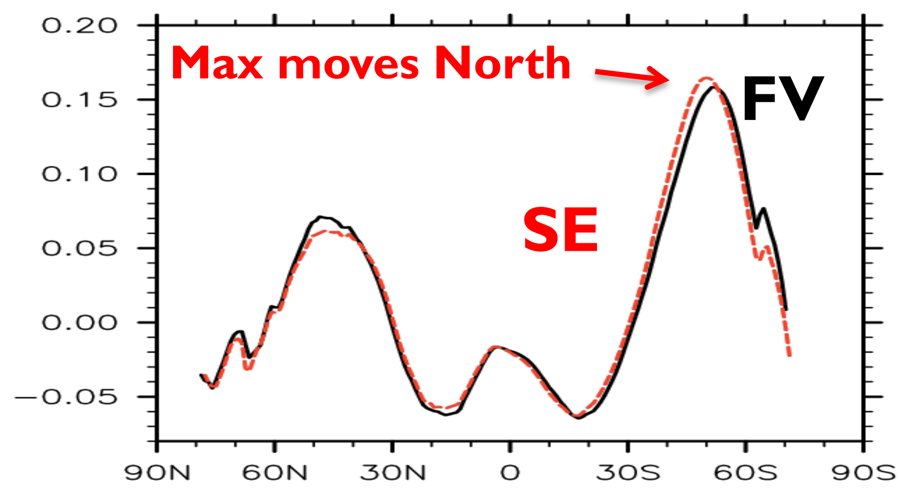
Spectral Element dycore development (CESM1.2, 2013)

- **In CAM standalone: Finite Volume (FV) and Spectral Element (SE) dycores produces very similar simulations.**
- **In coupled mode: SSTs stabilize 0.5K colder with SE dycore**

SSTs (K)



Zonal Surface Stress (N/m2)



Changes in location of upwelling zones associated with ocean circulation is responsible of the SST cooling

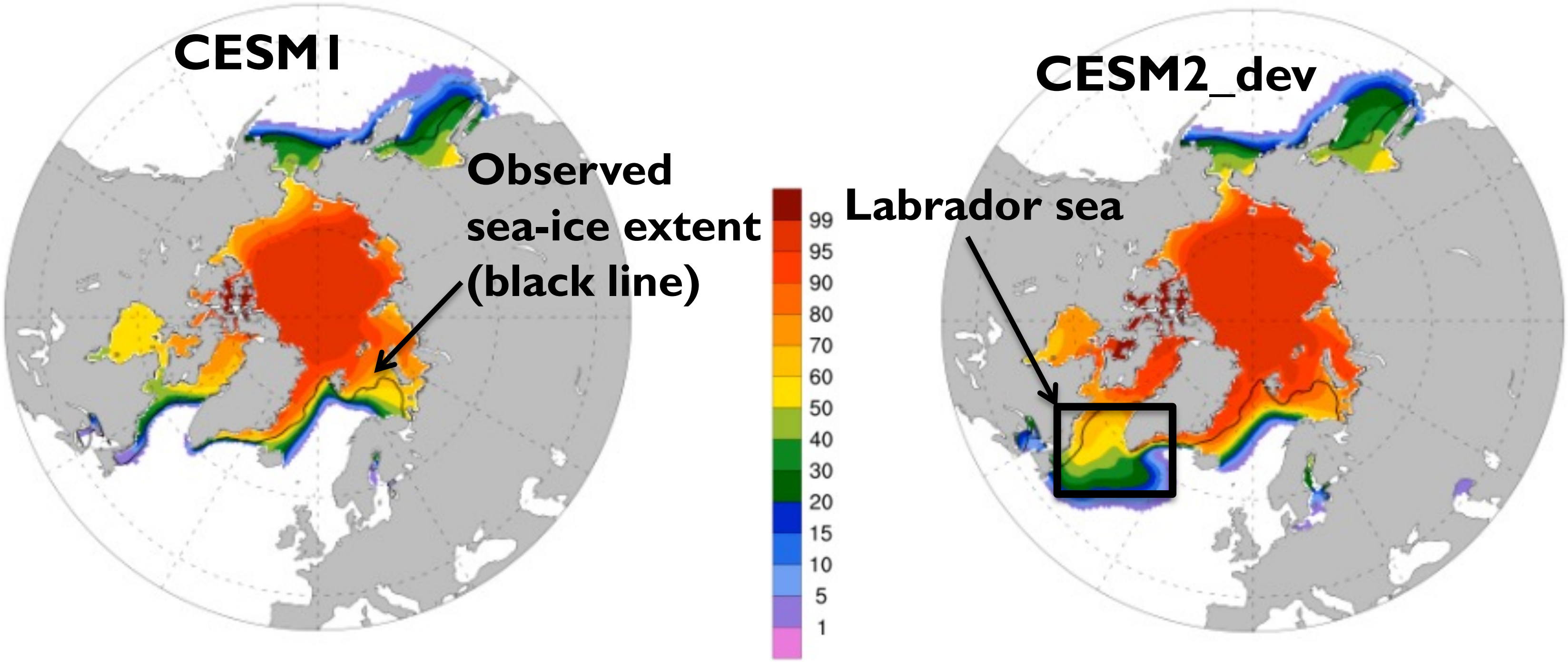
Coupling = Unleashing the Beast

Example of unleashing the beast (3)

The Labrador Sea issue (CESM2 development, 2016)

- **The Labrador Sea was freezing in CESM2_dev.**

Sea-ice extent



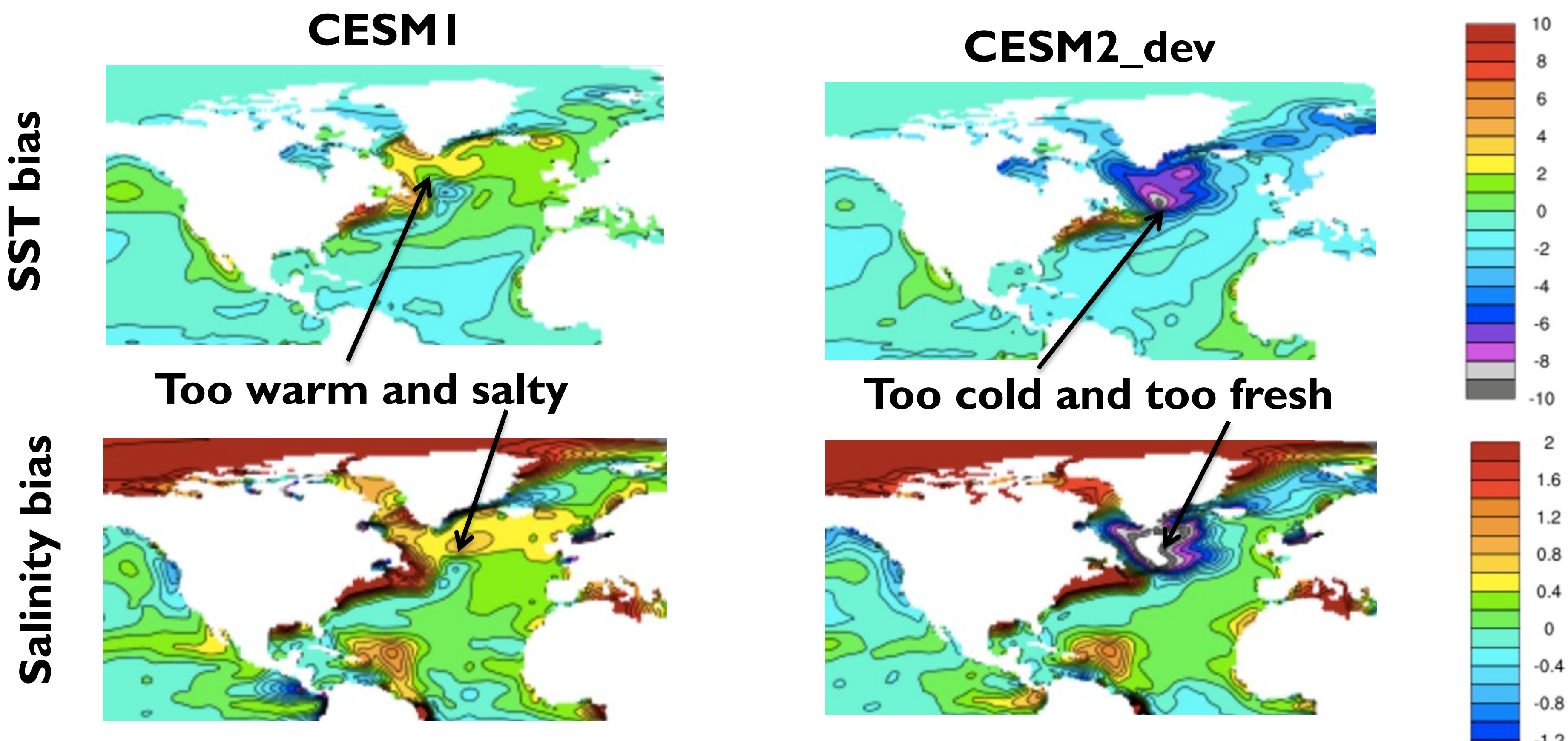
Sea-ice extent is close to obs.
Labrador sea is ice free

Labrador sea is ice-covered.
Can happen after 1 yr, 40 yr, 100^{+} yr

Example of unleashing the beast (3)

The Labrador Sea issue (CESM2 development, 2016)

- **Why was Labrador Sea freezing ?**



Too cold and too fresh South of Greenland => Labrador Sea freezes

Coupling = Unleashing the Beast

Summary

The Art of Tuning

**Tuning = adjusting parameters ("tuning knobs")
to achieve best agreement with observations.**

- **Tuning involves choice and compromise**
- **We learn a lot about the model while tuning**

The Art of Coupling

Three examples of coupling challenge

- **CESM1: cold SST bias in North Pacific with CAM5**
- **CESM1.2: SSTs stabilize 0.5K colder with SE dycore**
- **CESM2: Labrador Sea is ice-covered**